US009117771B2

(12) **United States Patent**
Seifert et al.

(10) **Patent No.: US 9,117,771 B2**
(45) **Date of Patent: Aug. 25, 2015**

(54) **INSULATION MATERIAL FOR INTEGRATED CIRCUITS AND USE OF SAID INTEGRATED CIRCUITS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 878 days.

(21) Appl. No.: **13/202,228**

(22) PCT Filed: **Feb. 3, 2010**

(86) PCT No.: **PCT/EP2010/051297**

§ 371 (c)(1), (2), (4) Date: **Aug. 18, 2011**

(87) PCT Pub. No.: **WO2010/094562**

PCT Pub. Date: **Aug. 26, 2010**

(65) **Prior Publication Data**

US 2011/0297869 A1 Dec. 8, 2011

(30) **Foreign Application Priority Data**

Feb. 20, 2009 (DE) 10 2009 001 044

(51) **Int. Cl.**
E04B 1/74 (2006.01)
H01L 21/312 (2006.01)

(52) **U.S. Cl.**
CPC ***H01L 21/312*** (2013.01)

(58) **Field of Classification Search**
CPC B01J 20/226; B01J 31/1691; B01J 20/024; B01J 20/0237; B01J 20/0244; C07F 5/06; C07F 5/08; H01L 21/32; H01L 21/3105; H01L 21/02107
USPC 252/62; 257/40; 540/465; 556/110, 118
See application file for complete search history.

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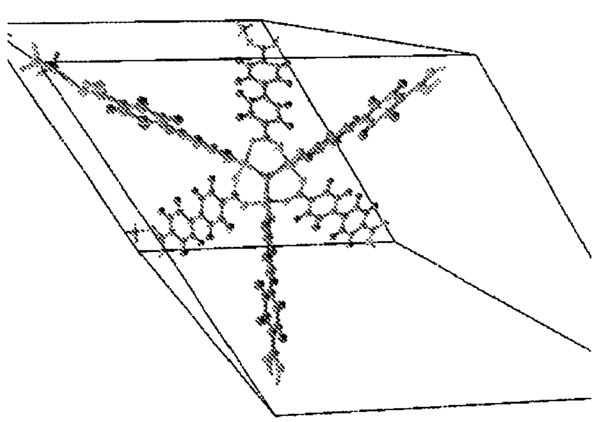
(57) **ABSTRACT**

The invention relates to the fields of microelectronics and materials sciences and concerns an insulation layer material for integrated circuits in microelectronics, which can be used, for example, in integrated circuits as insulation material in semiconductor components. The object of the present invention is to disclose an insulation material for integrated circuits, which has dielectric constants of k≤2 with good mechanical properties at the same time. The object is attained with an insulation material for integrated circuits, containing at least MOFs and/or COFs.

16 Claims, 1 Drawing Sheet



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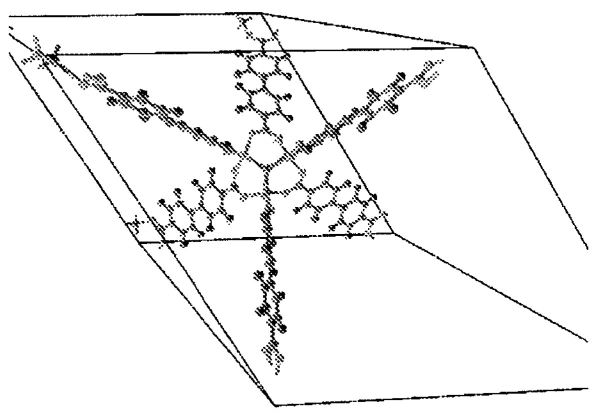

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INSULATION MATERIAL FOR INTEGRATED CIRCUITS AND USE OF SAID INTEGRATED CIRCUITS

The invention relates to the fields of microelectronics and materials sciences and concerns an insulation layer material for integrated circuits in microelectronics, which can be used, for example, in integrated circuits as an insulation material in semiconductor components.

The development and optimization of insulation materials with very good dielectric properties (dielectric constant k<3 if possible) is currently one of the most urgent tasks in microelectronics. This is above all because in this field there is a backlog of several years compared to the "roadmap" of the international semiconductor industry (M. Eizenberg, Interlayer Dielectrics for Semiconductor Technologies, Elsevier Acadamie Press, Amsterdam 2003, p. 5; R. D. Miller, Science 286 (1999) 421-422).

According to this "roadmap," a need has existed for years for insulation materials which have a static dielectric constant k<2 and in particular k<1.6, at the same time having an energy gap of ≥3 eV and a mechanical compressive modulus B of ≥6 GPa.

However, an insulation material of this type is not yet known.

The use of homogenous SiO_2 as a dielectric in microelectronics is known (Miller, R. D., Science 286 (1999) 421-422). SiO_2 can be applied, inter alia, by plasma-enhanced chemical vapor deposition (PECVD). Dielectrics of this type achieve values for the dielectric constant of k=3.9 to 4.2. With increasing package density and increasing power per chip, the dielectric SiO_2 can no longer be used in future due to the high k value.

Furthermore, porous SiO_2 materials are known as dielectrics (Zhang, J.-Y. et al., Mater. Sci. in Semiconductor Processing 3 (2000) 345-349; Murray, C. et al., Microelectronic Engng. 60 (2002) 133-141), these materials currently being still in the test phase for use. These materials can be applied, inter alia, by catalytic sol-gel polymerization of orthosilicate esters. The solvent is removed from the gel layer by supercritical extraction (aerogels) or eliminated by solvent exchange and drying (xerogels). Dielectrics of this type achieve values for the dielectric constant of k=1.7 to 3.6.

The disadvantages of these dielectrics are the very high production expenditure. The degrees of porosity at 50 to 80% are very high and unfavorably, the pores are open and to a great extent connected to one another. Furthermore, the pore size distribution cannot be controlled sufficiently well. Pores and channels of pores connected to one another can form, which lead to the electrical connection of adjacent metal conductors that should be separated by the dielectric. This can lead to the failure of the chip.

The use of homogenous polymers as dielectrics is also known. However, only the highly fluorinated alkane derivatives achieve k values of <2.2, such as PTFE, for example, with k values of 1.9 to 2.1 (Wang, J. et al., Scripta mater. 42 (2000) 687-694). PTFE layers can be produced from surfactant-stabilized aqueous microemulsions.

Furthermore, according to DE 102 53 855.7 A1 an insulation layer material for integrated circuits in damascene architecture is known, which are composed of fullerenes arranged separated from one another by molecules or groups of molecules. The molecules or groups of molecules are thereby connected to the fullerenes at least at two points via chemical and/or physical interactions. This insulation layer material has k values of <4.0 with an adjustable pore size of <2.0 nm.

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The known insulation materials for integrated circuits are produced either by CVD or spin-on processes.

All of the known solutions have in common that their mechanical strength deteriorates significantly with lower k values.

Furthermore, metallo-organic frameworks (MOFs) (O. M. Yaghi, et al., Nature 423, 705 (2003)) and covalent frameworks (COFs) (A. P. Coté, et al., Science 310, 1166 (2005)) are known. These materials are coordination polymer compounds, which are linked to form a regular three-dimensional network. The prototype of the metallo-organic framework is MOF-5, in which Zn_4O structural units are linked via terephthalate bridges to form a zeolite-like cubic three-dimensional network (H. Li, et al., Nature 402, 276, (1999)).

The special advantage of these MOFs and COFs is their extremely large specific surface, because of which they have previously been used to adsorb and store gases and as sensors.

The known properties and applications of MOFs (www.mdpi.org/ijms/specialissues/frameworks) and COFs (A.P. Câté, et al., Science 2005, 310, 1166-1170) are based on their enormously high specific surface of in some cases several 1000 m^2/g. Some MOFs have already been commercially produced and characterized in corresponding data sheets, for example, given in data sheets of BASF/Sigma-Aldrich (www.Sigmaaldrich.com/Produkte, product numbers 688738, 688614).

No information on or indications of particularly low dielectric constants of MOFs and COFs are known from the prior art.

The object of the present invention is to disclose an insulation material for integrated circuits, which has dielectric constants of k≤2 with good mechanical properties at the same time.

The object is attained through the invention disclosed in the claims. Advantageous embodiments are the subject matter of the subordinate claims.

The insulation material according to the invention for integrated circuits contains at least MOFs and/or COFs.

Advantageously, exclusively MOFs form the insulation material.

Furthermore advantageously, the insulation material is composed of MOFs and/or COFs and adhesives, such as parylene.

Likewise advantageously, MOFs are present within a network in crystalline to random, free form.

And also advantageously, MOFs are present with an isoreticular cubic network with analogous structural principle (IRMOFs), these being still more advantageously IRMOF-1 FCC, IRMOF-1 SC, IRMOF-10, IRMOF-M11, IRMOF-M13, IRMOF-14.

It is also advantageous if a metal atom is present as the central atom in the network, still more advantageously Cu or Zn being present as a metal atom.

In the use according to the invention, MOFs and/or COFs are used as insulator material with dielectric constants of k≤2 for integrated circuits.

Advantageously, exclusively MOFs are used as insulator material with dielectric constants of k≤2 for integrated circuits.

Furthermore advantageously, MOFs and/or COFs are used as insulator material with dielectric constants of k≤2 for integrated circuits and adhesives, still more advantageously parylene being used as an adhesive.

Likewise advantageously, MOFs with a network in crystalline to random, free form are used as insulator material with dielectric constants of k≤2 for integrated circuits.

It is also advantageous if MOFs with an isoreticular cubic network with analogous structural principle (IRMOFs) are used as insulator material with dielectric constants of k≤2 for integrated circuits.

And it is also advantageous if MOFs or COFs with a central metal atom in the network are used as insulator material with dielectric constants of k≤2 for integrated circuits, still more advantageously Cu or Zn being used as metal atom for insulator material with dielectric constants of k≤2 for integrated circuits.

With the solution according to the invention, MOFs and COFs are employed and used as insulation material or in insulation materials for the first time.

The particularly low dielectric constants and their combinations have not been hitherto known with sufficiently good mechanical properties of the MOFs and COFs.

It has been established according to the invention that the MOFs and COFs, despite the presence of metal atoms, have very good to excellent insulating properties with particularly low static dielectric constants and at the same time still largely very good to excellent mechanical properties.

Depending on the special requirement, the aspect of the low dielectric constants or the aspect of the high compressive modulus can be emphasized in the selection of the MOFs or COFs to be used. In addition, the width of the energy band gap of the insulation material can also be varied with the selection of the MOFs or COFs.

Another advantage of the solution according to the invention is that the insulation material has a structural homogeneity with monodisperse pore sizes which is a further advantage compared to porous materials with finite width of the pore size distribution, which has an effect on product reliability in particular.

Likewise the signal delay can be improved with the solution according to the invention, which hitherto occurred as a limiting factor in integrated circuits. The reason for the signal delay is the product RC, that is, resistance times capacitance. The capacitance of the insulation material can be reduced by the use of porous to cellular materials. However, the mechanical strength must then be taken into account for the technological processes, which decreases with increasing porous or cellular content.

For the solution according to the invention the number, type, structure, size and/or length of the MOFs or COFs in the entire known bandwidth can thereby be applied and used.

However, it should be taken into account in the selection of the concrete materials that in each individual case the properties from the coordinates of the atoms in the elementary cell have to be newly determined.

Furthermore, it must be taken into account that the lower the polarizability of the interatomic bonds of the MOFs or COFs, the better the dielectric properties. Likewise, the dielectric properties are better, the lower the number of atoms per volume, whereby on the other hand on average the mechanical stability is impaired.

The invention is explained in more detail below based on an exemplary embodiment.

EXAMPLE 1

It shows:

FIG. **1** The arrangement of the atoms in the metallo-organic framework IRMOF-10

FIG. **1** shows the atomic structure of the metallo-organic framework IRMOF-10. The coordinates of the 166 atoms of the elementary cell are given in Table 1.

Table 1:

Coordinates of the atoms of IRMOF-10. Atom type, x, y, z coordinates as well as transformation matrix.

C	17.69545500	31.52594000	17.64974900
C	17.65012100	17.65330200	3.82251600
C	17.68594600	3.80991400	17.65938200
C	17.65899300	17.66272200	31.53854200
C	3.82249800	17.69872400	17.69584300
C	31.53852400	17.68905700	17.68559300
O	32.18758700	16.66136200	18.18911000
O	32.19274800	18.72468700	17.19541900
O	17.04497800	32.17148600	18.59328100
O	18.34957300	32.17146800	16.70818000
O	18.59389900	18.30374400	3.17728800
O	16.70839200	16.99962600	3.17677600
O	17.66837800	0.00825400	17.66836000
O	17.19619700	3.15569100	16.62350400
O	18.18914500	3.16101000	18.68727100
O	16.62325600	18.15298400	32.19257100
O	18.68661700	17.15934700	32.18774600
O	3.17689900	16.75487500	17.04580800
O	3.17712900	18.64045300	18.34985500
Zn	16.47421100	16.47901800	1.18434100
Zn	16.46673400	1.20790000	16.46654000
Zn	1.19556400	16.49004700	16.47437000
Zn	1.18405800	1.19996400	1.19529800
C	5.98969500	16.75332000	16.93237600
C	5.27866600	17.69865400	17.69273300
C	7.38055700	16.75989500	16.92475800
C	5.99116200	18.64469400	18.45158700
C	8.10432900	17.69861800	17.69071800
C	7.38165300	18.63778400	18.45666000
C	10.30234900	16.60814500	17.16288100
C	9.57861300	17.69808800	17.69105400
C	11.69333500	16.61196200	17.15400900
C	10.30174800	18.78826100	18.22087000
C	11.69231000	18.78463800	18.23142100
C	12.40604200	17.69845900	17.69294500
H	5.44004900	16.01298800	16.33879200
H	5.44162200	19.38442600	19.04534800
H	12.24167300	15.76320000	16.72732100
H	12.24064800	19.63258800	18.65927600
H	9.77366400	19.65839200	18.62594200
H	7.90924200	19.37283200	19.07465200
H	7.90759800	16.02543000	16.30556400
H	9.77467100	15.73720100	16.75825100
C	18.21282800	5.97857800	18.75439800
C	17.67679100	5.26680700	17.66547900
C	18.20233000	7.36944000	18.76081300
C	17.13619400	5.98126400	16.58112100
C	17.67424600	8.09390100	17.67087000
C	17.14460600	7.37195000	16.58000800
C	18.44144200	10.29241600	18.60833900
C	17.67507600	9.56837900	17.67067600
C	18.43642300	11.68308400	18.61229800
C	16.90917000	10.29093100	16.73159800
C	16.91634600	11.68144000	16.72231900
C	17.67801000	12.39383000	17.66519700
H	18.63930400	5.42937300	19.60261200
H	16.70961200	5.43329700	15.73237600
H	19.03136800	12.23301300	19.35162300
H	16.32193100	12.23025600	15.98195200
H	16.29052400	9.76272400	15.99697500
H	16.73965800	7.90056400	15.71035400
H	18.60681900	7.89632200	19.63191600
H	19.06070700	9.76532200	19.34335100
C	18.59529500	18.41583300	5.98992500
C	17.64994400	17.65572300	5.27866600
C	18.58852600	18.42322100	7.38078700
C	16.70392100	16.89662100	5.99093200
C	17.64964300	17.65736700	8.10432900
C	16.71061900	16.89131900	7.38144100
C	18.74001100	18.18564500	10.30219000
C	17.65001500	17.65724300	9.57863000
C	18.73642300	18.19457100	11.69317600
C	16.55991200	17.12765700	10.30188900
C	16.56373000	17.11715900	11.69248600
C	17.65010300	17.65551100	12.40600700
H	19.33573400	19.00941700	5.44045500

-continued

H	15.96427800	16.30286000	5.44123300
H	19.58522100	18.62140000	12.24130200
H	15.71581600	16.68948100	12.24100200
H	15.68962300	16.72269100	9.77396400
H	15.97564200	16.27323900	7.90897700
H	19.32306100	19.04230800	7.90786400
H	19.61081300	18.59040000	9.77438900
C	17.68523900	13.85089900	17.65876300
C	17.65005000	17.65264800	13.86335900
C	17.69557800	21.48497300	17.64976700
C	17.65846300	17.66300500	21.49746900
C	21.49748600	17.68987000	17.68516800
C	13.86335900	17.69888300	17.69557800
O	14.51544500	16.66553300	17.20307200
O	14.51487900	18.73052000	18.19262700
O	17.03997600	14.49833600	16.71109600
O	18.34207900	14.49425300	18.59798200
O	18.68363100	18.14497700	14.51532100
O	16.61860800	17.15551100	14.51502000
O	17.67005700	17.67845200	17.67007500
O	17.20321400	20.83297600	18.68327700
O	18.19264400	20.83334700	16.61821900
O	16.71079600	18.30833900	20.85006700
O	18.59764600	17.00614800	20.85409700
O	20.85404400	16.75072200	18.34206100
O	20.85012000	18.63755400	17.03985200
Zn	16.46371200	16.48216400	16.47726800
Zn	16.47709100	18.88477900	18.86622100
Zn	18.86307600	16.48522200	18.86311100
Zn	18.86627500	18.87111700	16.46351800
C	29.36717400	18.76728200	17.13619400
C	30.08164900	17.68287100	17.67661400
C	27.97648900	18.76836000	17.14478300
C	29.36996700	16.59395300	18.21277500
C	27.25455500	17.67744500	17.67438700
C	27.97910400	16.58757200	18.20241800
C	25.05759500	18.61671600	16.90917000
C	25.78007700	17.67767500	17.67514700
C	23.66706900	18.62610100	16.91625700
C	25.05591600	16.74001100	18.44142500
C	23.66524900	16.73612300	18.43633500
C	22.95457400	17.68327700	17.67794000
H	29.91507100	19.61604500	16.70959400
H	29.91922400	15.74573800	18.63916300
H	23.11832400	19.36648700	16.32178900
H	23.11523100	15.99679800	19.03119100
H	25.58292200	16.00491100	19.06068900
H	27.45225700	15.71650500	18.60697800
H	27.44792700	19.63806700	16.73997600
H	25.58583900	19.35125100	16.29047100
C	18.45162300	29.35740000	16.70376200
C	17.69262700	30.06980700	17.64978500
C	18.45681900	27.96690900	16.71061900
C	16.93244700	29.35869000	18.59517200
C	17.69087700	27.24411000	17.64976700
C	16.92500600	27.96781100	18.58854400
C	18.22079900	25.04660200	16.56008900
C	17.69112400	25.76980800	17.65019100
C	18.23126200	23.65598700	16.56374800
C	17.16279300	25.04612500	18.74013500
C	17.15383200	23.65512100	18.73638800
C	17.69280400	22.94234300	17.64999700
H	19.04534800	29.90701100	15.96403000
H	16.33888000	29.90823100	19.33562800
H	18.65901000	23.10756000	15.71578000
H	16.72703800	23.10687100	19.58516800
H	16.75810900	25.57382000	19.61104300
H	16.30590000	27.44080500	19.32306100
H	19.07482900	27.43937300	15.97564200
H	18.62594200	25.57456200	15.68990500
C	16.58103300	18.21217400	29.36712100
C	17.66537300	17.67164800	30.08163100
C	16.58000800	18.20365500	27.97645300
C	18.75432700	17.13552200	29.37002000
C	17.67095800	17.67406900	27.25457300
C	18.76077800	17.14596700	27.97914000
C	16.73172200	18.43926900	25.05756000
C	17.67079900	17.67332700	25.78007700
C	16.72224900	18.43202200	23.66703400

-continued

C	18.60842700	16.90701400	25.05595200
C	18.61224500	16.91194500	23.66526600
C	17.66502000	17.67025100	22.95457400
H	15.73227000	18.63877400	29.91501800
H	19.60252400	16.70908200	29.91927700
H	15.98184600	19.02643700	23.11828900
H	19.35149900	16.31701700	23.11528400
H	19.34363400	16.28790800	25.58297500
H	19.63188100	16.74142500	27.45234600
H	15.71035400	18.60849800	27.44783900
H	15.99724000	19.05807400	25.58578600

transformation matrix

0.000000	17.674087	17.674087
17.674087	0.000000	17.674087
17.674087	17.674087	0.000000

The properties of this IRMOF-10 are as follows:
Dielectric constant k=1.23
Mechanical compressive modulus B=6.00 GPa
Energy band gap E_g=3.07 eV.

EXAMPLES 2-6

The following metallo-organic frameworks show the properties listed in each case:

IRMOF-1, FCC	k = 1.37	B = 8.7 GPa	E_g = 3.73
IRMOF-1, SC	k = 1.39	B = 6.33 GPa	E_g = 3.66
IRMOF-M11	k = 1.45	B = 12.00 GPa	E_g = 4.91
IRMOF-M13	k = 1.50	B = 9.00 GPa	E_g = 5.49
IRMOF-14	k = 1.28	B = 5.90 GPa	E_g = 2.63

EXAMPLE 7

The covalent organic framework COF-108 shows the following properties: mass density: 0.17 g/cm^3 and specific surface (BET): 4210 m^2/g (H. M. El-Kalderi et al., Science 316 (2007) 268-272) and k=1.4.

The invention claimed is:

1. An integrated circuit comprising an insulation material, wherein the insulation material comprises
an adhesive, and
at least one MOF and/or at least one COF;
wherein
MOF means metallo-organic framework and
COF means covalent organic framework.

2. The integrated circuit according to claim **1**, wherein the insulation material consists essentially of one or more MOFs.

3. The integrated circuit according to claim **1**, in which the adhesive is parylene.

4. The integrated circuit according to claim **1**, in which the at least one MOF is present in a network in crystalline to random, free form.

5. The integrated circuit according to claim **1**, in which the at least one MOF forms an IRMOF;
wherein IRMOF means an isoreticular cubic network with analogous structural principle.

6. The integrated circuit according to claim **5**, in which the IRMOF is selected from the group consisting of IRMOF-1 FCC, IRMOF-1 SC, IRMOF-10, IRMOF-M11, IRMOF-M13, and IRMOF-14.

7. The integrated circuit according to claim **1**, in which a metal atom is present as central atom in the framework of the at least one MOF and/or at least one COF.

8. The integrated circuit according to claim **7**, in which the metal atom is Cu or Zn.

9. A method of insulating integrated circuits, comprising applying an insulator material comprising adhesive and at least one MOF and/or at least one COF, wherein the insulator material has a dielectric constants of $k \leq 2$ to reduce a signal delay in the integrated circuit;

wherein

MOF means metallo-organic framework and

COF means covalent organic framework.

10. The method of insulating integrated circuits according to claim **9**, wherein the insulator material consists essentially of MOFs.

11. The method of insulating integrated circuits according to claim **9**, wherein the insulator material further comprises an adhesive.

12. The method of insulating integrated circuits according to claim **11**, in which the adhesive is parylene.

13. The method of insulating integrated circuits according to claim **9**, wherein the insulation material comprises at least one MOF with a network in crystalline to random free form.

14. The method of insulating integrated circuits according to claim **9**, wherein the insulator material comprises at least one IRMOF;

wherein IRMOF means a MOF with an isoreticular cubic network with analogous structural principle.

15. The method of insulating integrated circuits according to claim **9**, wherein the at least one MOF and/or at least one COF comprises a central metal atom in the framework.

16. The method of insulating integrated circuits according to claim **15**, wherein the central metal atom is Cu or Zn.

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